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Assisting Public Organizations in Their Outsourcing Endeavors: A Decision Support Model

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This report is a formal draft or working paper, intended to solicit comments and ideas from a technical peer group.

This report contains preliminary findings, subject to revision as analysis proceeds.

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Introduction

In the last two decades politicians have in general believed that the U.S. Government has grown too bureaucratic and inefficient. They feel that a smaller government with fewer employees would better serve the public. One approach towards achieving this is to outsource some of the functions currently performed by government employees. From a political perspective, the outsourcing of public services may be claimed as an effort to achieve some or all of the following: save tax dollars, balance the Federal budget, fight bureaucracy, draw down public debt, support small business, and improve service quality. Also in the last few decades, businesses across the United States began contracting out some of their services, particularly Information Technology (IT) related service operations, in an effort to cut costs and refocus on their core functions. Given the industry trends and the perceived political benefits, politicians began applying pressure to Federal organizations to outsource also. This pressure continues today. Recently in the United States, the Federal Activities Inventory Reform (FAIR) Act requires a new look at every government function in every agency for the purpose of identifying additional functions for outsourcing.

The outsourcing of services in the public sector in other developed countries is even more prevalent than in the United States. Many European and Asian countries along with Australia and New Zealand face similar outsourcing challenges. For example in the European Union, Community Public Procurement Directives opened public contracts to competition and launched SIMAP, a public procurement information system aimed at making optimum use of new information technology for public procurements (Europa, 2001).

In addition to political pressure, public organizations are also outsourcing additional functions because of shortages of skilled human resources. For example, the NASA Glenn Research Center (NASA Glenn) in Ohio has shrunk in size from roughly 5000 to 3000 employees in the last decade or so. While the workforce has decreased 40 percent, the workload has not. As a result, additional outside support is necessary to accomplish their mission. This situation is common in other governmental organizations also. For Federal organizations, outsourcing motives are not directly linked to cost-cutting objectives, partially because the Federal Government is funded on voted budgets. Like NASA, other governmental organizations also may not consider cost savings as a primary motive but rather one factor among many that may influence the functions to be outsourced. Other such factors include political pressures, availability of skilled resources, and technology.

Existing outsourcing models do not capture the differences between public organizations and private industries outsourcing decision needs adequately since they usually have minimizing cost as the objective function. This study offers a decision support model for decision makers (DM) in public organizations, which takes into consideration the outsourcing motivates that are unique to them. The first step is to develop a list of factors and their priorities. The factors are then incorporated in the decision model to guide the organization in making more structured decisions about outsourcing. Once the functions to be outsourced have been determined, the number of contracts needs to be determined. The outsourcing decision model then also addresses the disposition of displaced employees, which are retained, at least in the short term, in many public organizations. This is accomplished by matching the displaced employee's skills with vacancies elsewhere in the organization.

In the following section, we provide a review of the literature regarding outsourcing practices in public organizations. Then we present the outsourcing decision flow and review the existing decision support models. This is followed by the development of a decision support model and three mathematical formulations. In later sections, the validity of the model is tested, using data from NASA Glenn, and the results of the sensitivity analysis are also reported. The managerial implications and the conclusions are presented in the last section.

Outsourcing Strategies at Public Organizations

When summarizing public sector outsourcing literature we find that the drivers for outsourcing are perhaps less clear than for private firms. Some suggest legislative actions and political pressures are primary drivers (Kakabadse et al., 2000a and 2000b) while others suggest the drivers are in fact similar to those of private industry (Domberger et al., 1999). The lack of internal skills, the access to external skills as well as budget issues are reported to drive some military outsourcing activities. The military, like some other government organizations, is also concerned with security issues (Richardson, 1997). The need to refocus on core mission or strategy is also mentioned by several authors as an important driver (Willcocks et al., 1997; Mehling, 1998; Champy, 1996; Gordon et al., 1997; OECD, 1997; and Avery, 2000).

Numerous recommendations are given in the literature regarding considerations for making outsourcing decisions. The importance of adequately planning, communicating, and executing the human resource phases of the outsourcing initiative is stressed by several authors (Roberts, 2001; Pinnington, 1995; Kakabadse et al., 2000b; Willcocks et al., 1997; and Lafferty et al., 2000). Legal issues such as procurement regulations and contractual arrangements have also been identified as critical and can be potential areas of weakness (Champy, 1996; Gordon et al., 1997; OECD, 1997; GAO, 1997; and Graham, 1996). Contract oversight and monitoring skills are recognized by the U.S. Government as one of its particular weaknesses (GAO, 1997). Lonsdale (1999) identified the lack of methodology as a weakness in many outsourcing initiatives. Some authors (Antonucci et al., 1998; Avery, 2000; Gordon et al., 1997; and Willcocks et al., 1995) imply that characteristics of functions may impact the decision for outsourcing. Some of these characteristics may include how integrated a function is, how structured it is, and how many employees it impacts. Public organizations should weigh every outsourcing decision to ensure that it helps to better serve the entire public in the long run and not favor any particular individual or industry in the process.

In addition to the literature mentioned above, an Organization for Economic Co-operation and Development (OECD) summary of outsourcing case studies reveals that governments outsource a wide range of functions, from IT functions to internal auditing to learning services and airport operations (OECD, 1997). Experiences with outsourcing in government have generally been positive, with service improvements occurring. Cost savings; however, are only about half of what the private sector achieves. A similar study (GAO, 1997) reports that one of the difficulties encountered with outsourcing, particularly in the United States, is the lack of skills within the public organization to manage and monitor outsourced functions. Other risks identified for outsourcing in the public sector include quality shedding (where the supplier finds ways to improve his profits by reducing quality), negative effects on employment, asset ownership issues, and accountability to the public. While managers in public organizations generally realize an accountability improvement in the particular function outsourced, they believe that there is a simultaneous decline in accountability to the public. The supplier works for the government and performs the functions to satisfy the government representative whereas a government employee works for the public and keeps their interests primary.

Another issue commonly discussed in the literature is whether outsourcing creates jobs. While some jobs may be created in the private sector, which would be advantageous during election campaigning, these same jobs are eventually lost in the public sector. Given the assumption that outsourcing is expected to improve productivity, the supplier should logically require fewer employees to perform the same functions and therefore the net result is a loss of jobs. In the United States, the elimination of civil servant jobs is said to be "one of the most contentious issues in public-sector outsourcing" (Gordon et al., 1997).

In summary, outsourcing literature identifies the following 13 dominant factors that influence outsourcing practices in public organizations: (1) how core a function is, (2) critical knowledge generation, (3) relative cost, (4) the degree of a function's integration, (5) the degree of a function's structure, (6) employee impact, (7) availability of external skills, (8) availability of internal skills, (9) manager preferences, (10) legal issues, (11) competitor actions, (12) potential for conflict of interest, and (13) internal and external political pressures. In a recent study (Kremic et al., 2003) has identified six additional dominant factors (a total of 19) affecting outsourcing decisions. The study is based on interviews with decision makers (DMs) in public organizations in the United States and indicates how the 19 dominant factors can be used to come up with an outsourceability index for each function under consideration. To briefly summarize, the indices are based on input from cognizant managers in the organization who rated the importance of each dominant factor and its applicability to the functions performed in the organization. The dominant factors are reiterated in table I along with the importance ranking of each factor as rated by NASA DMs using a scale of 1 to 10, where 10 indicates the most relevant factor to NASA Glenn at the time. The scale is arbitrary and a DM can choose another scale as desired. Once the relative importance of factors is determined, the DM evaluates the eligible functions for outsourcing against each of the dominant factors. This input is then utilized to determine the outsourceability index for each function. In the next section we introduce a decision support model, which will integrate these outsourceability indices into decision-making process.

Outsourcing Decision Flow

Figure 1 is a flow chart describing the outsourcing decision process. Every outsourcing decision begins with either a formal or a casual consideration of whether or not to outsource. Based on the DM's experiences, perceptions, and the current environment, the question of outsourcing will be further entertained or dismissed. If outsourcing is to be considered, the organization must perform some evaluation process to determine which of its functions, if any, are candidates for outsourcing.

Some of the factors to consider when making this determination are the relative costs of performing the function, how core is the function to the organization, the long-term strategy, and environmental factors such as sociopolitical perceptions.

Once the functions have been evaluated, decisions can be made about which ones to actually outsource. If any functions are to be outsourced, two additional decisions are required. One decision is how to obtain the service and the other is what to do with the displaced employees.

Services are acquired through contracts. In some cases existing contracts, which are already in place, can be modified to include the newly outsourced functions. In many cases however, new contracts need to be generated. In those cases, the functions must be grouped into contracts in a manner that minimizes costs and risks, yet maximizes the potential benefit from economies of scale and function synergies. The degree of reliance on a supplier is also important to consider.

The next decision is to determine what to do with the employees that are displaced when a function is outsourced. In public organizations, employees are often reassigned to other functions. This is unlike many private organizations where there is a greater tendency to eliminate the displaced employees by transferring them to the service provider or by laying them off. In this model it is assumed that all employees are reassigned back into the organization although this is not a requirement for the model. Reassignments are made, based on an employee's skills and experience, on his or her rank in the organization, and on positions available to be filled. With each new outsourcing contract, there may be positions created to monitor contractor performance. This can be another opportunity for employee reassignment.

Yet another reassignment opportunity is created if there is a need to capture supplier skills or knowledge of a critical function. The organization may want to maintain their knowledge or skills in a function even though it is outsourced. In such cases they may want to dedicate staff to work with the supplier in order to capture that knowledge and maintain a skill.

All these issues need to be considered when deciding what and how to outsource and it is a challenging endeavor for a DM, especially when there is a lack of methodology to follow (Lonsdale, 1999). In order to help systematize the DM's decision process as well as to guide him/her in understanding the implications of the decision on the workforce and contract, we present a decision support model for outsourcing initiatives. This model is explained in detail in the next section.

A Decision Support Model for Public Organizations

There has been several decision support models developed in the literature for assisting organizations in outsourcing practices in private sector. For example, Lonsdale (1999) discusses a risk minimizing approach to outsourcing. His model recommends understanding and protecting the sources of the organization's competitive advantage and realizing the potential for dependency. Jennings (2002) assumes that outsourcing is undertaken to achieve competitive advantage. He develops a conceptual model that considers the organization's capability and its competitive environment. Cost, supply environment, and technology are factors that influence capability. Rao and Young (1994) develop a model for outsourcing in the logistics field. They identify several factor sets to be considered in such an environment. The centrality/criticality of the function, cost, technology and complexity, risk, and market relationships comprise the factors. Arnold (2000) develops an "integrated model" using both transaction cost economics and a core competence approach. Arnold suggests that managers should answer the following three questions to determine if a function should be outsourced; these are (1) "Is the activity highly specific?" (2) "Is the activity strategically important?" and (3) "Is the activity a core competence…?" Although the model is rather broad, it does provide guidance to determine what factors affect a decision and in which way. Dekkers (2000) develops a conceptual outsourcing model for manufacturing industries. His objective is to develop a tool for outsourcing decisions. A process mapping approach is used to link manufacturing functions with outsourcing decisions. Finally, Yang and Huang (2000) used Saaty's (1980) analytical hierarchy process (AHP) to support IT outsourcing decisions.

The existing models in literature provide differing perspectives of how outsourcing decisions and factors relate to each other and to the organization. They reinforce the importance of certain factors to consider. Moreover, they provide some guidance and increased detail of the outsourcing problem. However little information is given on the success of these models or how managers used them. Furthermore, the models lack many of the factors that are important to public organizations. First, to the authors' knowledge, none of the models in the literature specifically address the political factors faced by public organizations. Many existing models also lack the ability to determine what factor(s) is of greatest importance to the outsourcing DM. Furthermore, many existing models assume that competitive advantage, financial gain, or other cost and strategy objectives drive the outsourcing initiatives, which is not an accurate assumption for many public organizations. The drivers may be quite different in the public organization. Third, existing models fail to address what happens internally after it is decided to outsource a function considering that public organizations tend to retain the employees much more so than private industry.

The model developed in this study seeks to address these limitations. The model is presented in figure 2. It is referred to as the Decision Support Model for Public Organizations (DSMPO). It depicts how a public organization's outsourcing decision may occur.

Successful implementation of the DSMPO requires information on the work being performed, the impacted employees, cost structures, departments and facilities, and skills. These records or sources of information are shown in figure 2 and identified by a gray background color. The information is collected into electronic storage and organized for use by the Integer Programming (IP) solvers.

There are three IP formulations in the model, labeled in the DSMPO as IP1, IP2, and IP3. IP1 recommends which functions to outsource. As indicated by the DSMPO, the results of IP1 will be reviewed by the DM who may then determine that adjustments are necessary. Once the functions planned for outsourcing are final, they become input for the other two formulations. Prior to the partitioning of functions into contracts, the DM may choose to add some of the functions to existing contracts. If this is the case, those functions are taken out of the set to be outsourced. The remaining functions are then partitioned into new contracts by IP2. The DM may also choose to review the results of IP2. IP3 looks at the people displaced when functions are outsourced and seeks to reassign them. The output of IP3 is a list of reassignments and once again the DM has the option of reviewing and adjusting the output.

Three parties play a role in applying the model and inputting the data. The primary interface to the model is the model user who has detailed knowledge of the model and the internal relationships. He/she collects data and enters the information about the organization. Organizational representatives (managers) provide most of the information. The third party is the DM(s) who provides input and ultimately makes the decisions.

In the following subsections, the three IP formulations are discussed in more detail.

IP1 Formulation

IP1 assumes that the public organization will outsource as many functions as its outsourcing budget will allow as long as it does not threaten the loss of critical skills (its core competence). Recall that for public organizations, outsourcing will initially cost more money assuming that many of the employees are retained.

The objective function for IP1 seeks to maximize the outsourceability value of the set of functions outsourced, subject to internal constraints. The model seeks to choose functions with high values of outsourceability index, W_{ij} where,

$$W_{ij} = \sum_{f=1}^{F} R_f V_{ijf} \qquad \forall \text{ i, j}$$

R_f is the importance ranking for factor f, f = 1, …, F, and V_{ijf} is the evaluation of function i in department j for each factor f. For each function i in department j, the outsourceability index is calculated using a weighted factor scoring method where the 19 factors are weighted by a DM according to level of importance and multiplied by a score (V_{ijf}) each function gets based on how well it relates to that factor (Kremic et al., 2003). It should also be noted that some distinct functions in an organization are related such that it only makes sense to either keep them all in-house or all outsourced together. This type of relationship between functions is captured by so called “associated functions” sets in the model.

IP1:

$$\text{Max} \quad \sum_{j=1}^{J} \sum_{i=1}^{I} W_{ij} X_{ij}$$

Subject to

(1) $$\sum_{j=1}^{J} \sum_{i=1}^{I} C_{ij} X_{ij} \leq B$$

(2) $$\sum_{j=1}^{J} \sum_{i=1}^{I} S_{ijk} X_{ij} < \sum_{j=1}^{J} \sum_{i=1}^{I} S_{ijk} \qquad \forall\, k \in K,$$

(3) $$x_{ij} = x_{nl} \qquad \forall\, (i,j) \text{ and } (n,l) \in G_m$$

(4) $$\sum_{j=1}^{J} \sum_{i=1}^{I} X_{ij} \geq 1$$

(5) $$X_{ij} \in \{0,1\} \qquad \forall\, i, j$$

The decision variables of the formulation are

X_{ij}: An integer variable that has a value of 1 if function i in department j is outsourced, and 0 otherwise.

The parameters used in the formulations are

B: Outsourcing budget.

C_{ij}: Cost of performing function i in department j.

G_m: A set of m associated functions that are to be outsourced (or kept in-house) as a group, where m = 1, …, M.

I: Total number of functions being considered for outsourcing.

J: Total number of departments or facilities where the functions are performed.

K: Set of critical skills.

S_{ijk}: Has a value 1 if function i in department j employs critical skill k, and 0 otherwise.

Constraint (1) ensures that the budget to pay a contractor for the newly outsourced services is not exceeded. The second constraint ensures that not all functions that use a critical skill are outsourced in order to prevent the loss of core competency. Constraint (3) keeps associated functions together (either outsourced or kept inhouse) while the last constraint (4) forces at least one function to be outsourced. Constraint (4) is added to ensure that the model will identify at least one function to outsource, as this is the basic premise for using the model in the first place. Recall that this model is developed for the public organizations with fixed budgets, retained employees, and political pressure to outsource. The underlying assumption is that it is desired (or perhaps required) to outsource additional functions. Note that IP1 is a knapsack problem with side constraints.

Once the functions to be outsourced are determined they must be put into contracts; the purpose of the second formulation, IP2.

IP2 Formulation

This formulation is based on set partitioning problems and is similar to the political districting problem. The objective function seeks to minimize cost by placing all functions into the minimum number of contracts such that no constraints are violated. Each additional contract would require an additional set of contract generation, procurement, and monitoring and maintenance costs. Since neither the number of functions being outsourced nor the estimate of implementing them through a contractor changes, it follows that minimizing the number of contracts is a reasonable approach in attempting to minimize contract-related costs. Fewer contracts also implies more functions per contract which, depending on function similarity, may increase synergy and further minimize cost. The primary input for IP2 is a list of functions to outsource. The output of IP2 is a list of contracts and the functions included in each.

IP2:

$$\text{Min} \sum_{q=1}^{Q} CG_q Z_q$$

Subject to

(7) $$\left(\sum_{m=1}^{M} C_m e_{mq} \right) Z_q \le MDV \qquad \forall\, q,\ q = 1, \ldots, Q$$

(8) $$e_{rq} Z_q = e_{sq} Z_q \qquad \forall\, (r,s) \in G_v \text{ and } \forall\, q, v,\ v = 1, \ldots, V$$

(9) $$\left(\sum_{p=1}^{|U_y|} e_{pq} \right) Z_q < |U_y| \qquad \forall\, p \in U_y, \text{ and } \forall\, q, y,\ y=1, \ldots, Y$$

(10) $$\sum_{q=1}^{Q} e_{mq} Z_q = 1 \qquad \forall\, m,\ m = 1, \ldots, M$$

(11) $$Z_q \in \{0,1\} \qquad \forall\, q$$

The decision variables for the formulation are

Z_q: An integer variable that has the value of 1 if the contract q is in the partition plan, and 0 otherwise. $q = 1, \ldots, Q$

The following parameters are used

C_m: Estimated cost for a contractor to perform function m.
CG_q: Total cost to generate and maintain contract q.
e_{mq}: Has a value 1 if function m is in contract q, and 0 otherwise.
G_v: A set of v associated functions that are to be outsourced or (kept inhouse) as a group, where v = 1, …, V.
M: Total number of functions being outsourced.
MDV: The maximum dollar value of a single contract.
U_y: A set of functions where the entire set cannot be in any given contract. Y = 1, .., Y, and $|U_y|$ indicates the size of the set.
Q: The maximum possible number of contract combinations in the plan.

Q can be calculated from the total number of functions outsourced, M, by the following:

$$Q = M!\left(\sum_{n=1}^{M-1} \frac{1}{n!\,(M-n)!}\right) + 1 \tag{12}$$

Note that Q is an upper bound on the number of possible contracts to choose from and it increases combinatorially as the number of functions to outsource increases.

The first constraint limits the contract size of any contract, q, to a maximum dollar value (MDV). It is assumed that the cost of each function is C_m regardless of which contract it is part of. The second constraint ensures that associated functions are to be treated as a group and are assigned to the same contract. In many cases, however, not every contract option is desired. For example, it might not be desirable to include too many or the wrong combination of functions in a contract and give it to a single supplier resulting in a power advantage or a conflict of interest. These preferences are imposed in the formulation by constraint set (9). Constraint (10) ensures that every function is included in one and only one contract.

IP3 Formulation

The third IP formulation reassigns displaced employees to other functions in the organization. Using employee rank, seniority, and skills, the formulation reassigns employees to vacant positions. Some new functions may be created as a result of outsourcing, such as functions to capture knowledge learned by the contractors. These are referred to as knowledge capture (KC) functions. KC functions have priority and therefore employees are reassigned to KC functions before they become available for assignment to other functions in the organization. If an employee is not qualified to be placed into any available function, he/she becomes “unassigned.” The disposition of unassigned employees is left for DMs to decide.

Note that the public employee reassignment problem must handle assignments where multiple functions are assigned to an employee, multiple employees to one function, or both, and the assignments are not necessarily in whole units (the employees can be assigned to functions at fractions of their full effort). The minimum unit of assignment is identified as k where k is equal to one-fourth full-time equivalent (FTE) for convenience and practical applicability. The formulation assumes that employees are not assigned overtime and therefore have a maximum of 1 FTE, or 4 k to assign.

IP3:

$$\text{Max} \sum_{i=1}^{I} \text{EP}_i \sum_{j=1}^{J} \text{RP}_{ij} \sum_{k=1}^{K} k\ \text{Y}_{ijk}$$

Subject to

(13) $$\sum_{j=1}^{J} \sum_{k=1}^{K} k\ \text{Y}_{ijk} \le \text{ERC}_i \qquad \forall\ i,\ i = 1, \ldots, I$$

(14) $$\sum_{i=1}^{I} \sum_{k=1}^{K} k\ \text{Y}_{ijk} \le \text{FRC}_j \qquad \forall\ j,\ j = 1, \ldots, J$$

(15) $$\text{ERK}_i\text{Y}_{ijk} \ge \text{TRK}_j\text{Y}_{ijk} \qquad \forall\ i,j,k,\ k = 1, \ldots, K$$

(16) $$\sum_{l=1}^{|\text{TSK}_j|} \text{Z}_{il}\left(\sum_{k=1}^{K} \text{Y}_{ijk}\right) = |\text{TSK}_j| \cdot \left(\sum_{k=1}^{K} \text{Y}_{ijk}\right) \qquad \forall\ i,j, \text{ and } l \in \text{TSK}_j$$

(17) $$\sum_{k=1}^{K} \text{Y}_{ijk} \le 1 \qquad \forall\ i,j,$$

(18) $$\sum_{i=1}^{I} \sum_{k=1}^{K} k\ \text{Y}_{ijk} = \text{CE}_j \qquad \forall\ j \in M$$

(19) $$\text{Y}_{ijk} \in \{0,1\} \qquad \forall\ i,j,k$$

The decision variables for the formulation are

Y_{ijk}: An integer variable that has the value 1 if employee *i* is assigned to function *j* at level *k*, and 0 otherwise.

Note that the parameters used in IP3 do not correspond with those of IP1 and IP2. For example, *i* represents a function in IP1 and IP2, while *i* represents an employee in IP3. The following parameters are used in formulation IP3:

CE_j: Total effort to be dedicated to knowledge capture of function *j*. CE_j is in units of *k*.
EP_i: Indicates the benefit of assigning employee *i* to function *j* at level *k* where $EP_i \in (0,1)$.
ERC_i: The maximum amount of employee *i*'s time that can be reassigned, in units of k.
ERK_i: Rank of employee *i*.
FRC_j: Maximum capacity available in function *j* for employee reassignment, in units of *k*.
I: Total number of employees.
J: Total number of functions available for assignment to employees.
K: Reciprocal of the fraction of an FTE that an employee can be assigned to a function.
M: Set of knowledge capture functions.
TRK_j: The rank required of an employee to be qualified to perform function *j*.
RP_{ij}: Reassignment penalty, has a value of 1 if $ERK_i = TRK_j$, and .991 otherwise.
TSK_j: Set of skills required to perform function *j*. $|TSK_j|$ indicates the size of the set.
Z_{il}: Has a value of 1 if employee *i* possesses skill *l*.

The objective function seeks to maximize the benefits of reassignment and is subject to several constraints. Benefits are realized by simply finding assignments for employees. However, preference (via a larger EP_i) is given to employees of higher rank, longer experience, and for reassignments that consume more of their available time (the closer to a full time reassignment the greater the benefit). The first constraint limits how much of an employee's time is reassigned. The reassignment cannot exceed what he/she has available. The second constraint ensures that the capacity of a function to absorb employee effort is not exceeded. The next constraint ensures an employee for reassignment to a function is qualified for the function. This constraint ensures that for each function an employee is reassigned to, his or her rank is greater or equal to the rank required to perform the function. Constraint (16) determines if an employee is qualified to perform a function. This constraint ensures that the employee possesses all the necessary skills required by a function. Constraint (17) ensures that an employee is not assigned to the same function more than once. The summation allows a person to be assigned to a function a total of one time. This constraint will also prevent a person from being over-assigned (assigned overtime) to any given function. The last constraint ensures that the knowledge capture functions have reassignment priority and that those positions are completely filled.

The DSMPO is designed as three sequential IP's rather than one large one. This not only allows for DM intervention but also brings flexibility and practicality to the decision-making process. The functions that are to be outsourced in IP1 limits the sizes of IP2 and IP3 formulations, both of which are combinatorial in nature. For example, in IP2, there are 1023 possible contract combinations to evaluate for 10 functions to outsource. As the number of functions increase the number of combinations to consider increases exponentially and becomes very difficult if not impossible to solve. Similarly, the number of possible functions to outsource has a direct impact to the size of IP3. Assuming for convenience that 14 employees can potentially be assigned to 18 functions at four levels of effort requires 1008 possible combinations to evaluate, not to mention that each employee may have one or more skills which must be matched to functions requiring those skills.

Further, deciding what to outsource is more of a strategic decision compared to deciding on the number of contracts and the disposition of employees, both of which are more operational. Using a single model could cause the strategic issues to be driven by operational matters.

Application of DSMPO to NASA Glenn

In order to test the validity of the model, data was collected from NASA Glenn, one of the fourteen NASA centers. NASA Glenn is perhaps best known for its expertise in propulsion technologies such as turbomachinery. The Center is roughly organized into major program offices and service/performing organizations. The data that was collected comes from a service/performing division. The division is composed of 112 people organized into six departments. The main role of the division is to manage and maintain the center's infrastructure and the 100-plus structures at the complex.

The division's tasks can be broken into 40 functions. However nine of those were determined by managers to be inherently governmental and not to be outsourced. This leaves thirty-one functions that may be outsourced. Note, however, the same functions may be performed in more than one department in this division. For example, the same type of inspection function can be done in both the Facilities Engineering department and the Construction Management department.

The skills resident at NASA Glenn were identified in a survey conducted in the year 2000 by the in-house human resources organization. Thirty-seven different skills are found in the division as defined in the survey. This same list of 37 skills is also used in determining what skills are required to perform each function. The division head selected 7 of the 37 skills as critical. The functions that use the critical skills cannot all be outsourced.

The division receives financial resources from several sources. A significant percentage of the incoming funds are set aside to pay for ongoing contracts and predetermined needs. The division has very limited funds to re-allocate in the near term. This fact limits the amount of new outsourcing that can be initiated.

Data Collection

The data required to implement the formulations is collected from managers within the division. The division leader determined the relative importance of the 19 dominant factors (shown in table I) to the organization in the current environment. The division leader also determined that the outsourcing budget is $1 M based on the current level of discretionary funding. Other budget-related information is provided by appropriate managers.

Managers in the organization also provided the data on employee qualifications, the functions performed by their organization, the functions each employee performs and how much effort they spend on each function, which functions are critical, and any other data needed. They also evaluated each of the functions performed in their respective organizations against the 19 factors. Preprepared forms were used to aid in data collection and all the managers were given the same forms. The collected data was then transferred to a spreadsheet and checked. Figure 3 shows what the data may look like.

Employee salaries and benefits range from roughly $50,000 to over $100,000. Since some functions require more people than others, the cost to perform functions depends not only on wages but also on the number of FTE's assigned to the function. Function costs range between $50 K and $1.3 M per year, however, most functions cost between $100 K and $250 K per year.

Roughly half the functions within the division are associated with one or more other functions. In particular Department 4 has 7 of its 10 functions associated together. The effect of these associations is that IP1 will treat them as one large function when it comes to cost.

A list of functions that can absorb displaced employees is also collected. In total; 18 functions are identified that can absorb employees for up to 111 k units of effort.

In general, the data provided by the managers was complete and appears consistent. Consistency refers to the agreement of related data. For example, the amount of time spent performing functions within the departments was equal to the time available.

Computational Results

The IP formulations were modeled using the Lingo Solver developed by Lindo Systems. Each IP formulation is modeled and solved separately. IP1 recommends 10 functions from various departments to outsource. IP2 recommends that all the functions be placed into one contract and IP3 reassigns 10 of the 14 employees impacted to other functions.

The 10 functions recommended for outsourcing are shown in table II. The total estimated cost to perform the functions is $974,300 which leaves just $25,700 slack in the budget constraint of $1 M. The solution is reached in less than 4 sec on a Pentium III computer.

The DM chose not to adjust the outputs of any of the formulations so the 10 functions are fed as inputs into IP2. Other inputs into IP2 include the maximum dollar value of a contract, the respective costs to perform the functions and any disassociations the functions may have.

While the task of placing functions, into contracts may seem simple enough, it is a difficult problem to solve with integer programming. The placing of elements within sets falls within the general class of set covering problems. The challenge with this type of problem lies in the large number of possible combinations of functions.

A heuristic was developed to reduce the problem to a more manageable size. The heuristic estimates the number of contracts that may be required and is based on the maximum contract dollar value (MDV) parameter, the average cost of the functions, and the total cost to perform all functions. The estimate is determined as shown in the pseudocode below. The use of the heuristic assumes that the number of disassociations is small. If this is not the case, the number of contracts required may need to be increased.

A lower bound for the number of contracts may also be estimated from the number of disassociations and the MDV. For example, if the MDV is one-fifth of the value of the functions being outsourced, then it is known that the lower bound, or the minimum number of contracts required, is five. The pseudocode for the heuristic is as follows.

<u>Pseudocode</u>

Step 0. Let X = MDV / AFC

Step 1. Determine estimates for the minimum number of contracts
Let EST1 = (NF / X) + 1, rounded down
Let EST2 = (TFV / MDV) + 1, rounded down

Step 2. EST = Max {EST1, EST2}
Where: MDV is the maximum contract dollar value,
TFV is the total cost to perform all functions being outsourced,
AFC is the average cost of the functions being outsourced,
NF is the number of functions
–MDV, TFV, NF, and AFC are known.
–EST1 and EST2 are estimates for the minimum number of contracts and the larger is to be selected.

For the NASA Glenn data, IP2 determines that the optimum solution is one contract. This occurs because there are no disassociations for the functions that are outsourced and because the MDV is large enough to accommodate all the functions. The computing time was approximately 53 sec, much larger than what it took to solve IP1.

Moving to IP3, the outsourcing of 10 functions displaces some portion of the time of 14 employees. In total this results in 45 k units of effort to be reassigned. There are 18 functions that can absorb displaced employees, twelve of which are functions not recommended for outsourcing and six are functions that are outsourced but are selected as KC functions. The 18 functions have the combined capacity to absorb 111 k units of effort.

One of the challenges with this problem is the large number of combinations and constraints. Any of the 14 employees can potentially be assigned to any of the 18 functions at any of 4 levels of effort.

Therefore there are 14 * 18 * 4 (for a total of 1008) combinations of people, functions, and levels. Also consider that each employee may have 1 or more of 37 potential skills, which must be matched to functions requiring 1 or more of the 37 potential skills. Because of the large number of constraints, preprocessing is used to reduce the problem size. For example, instead of using the list of the 37 skills, a shorter skills list is defined based on only those skills required to perform the absorbing functions. This reduces the number of constraints in the model by over 15000 yet does not affect the quality of the solution.

With preprocessing, IP3 is solved to optimality in less than 2 sec on a Pentium III PC. Of the 45 k units of effort to be reassigned, the model reassigns 29 k units. Eight of the 14 employees have all their available time reassigned. Two additional employees have part of their available time reassigned and four employees are not reassigned. Table III presents the solution.

Sensitivity Analysis

In this section we examine the effect of variations in the input data on the optimum solutions to IP1, IP2, and IP3. Table IV captures the majority of solution changes to IP1 that were observed. All parameters in the formulation were systematically changed to practical limits. Further, constraints were also systematically eliminated and reinserted and the changes in the value of objective function were recorded. In total, 40 problem instances were solved. For most changes to the input of IP1 the solution remains as 10 functions to outsource. Although the value of the optimum solution changes by varying parameters and constraints, many of the same functions remain in the recommended set.

In the table, we report 9 of the 40 problem instances that resulted in noteworthy changes in the original solution to IP1. In the second column we report the type of modifications made to the model parameters and constraints, and in the last column we report the effect of these changes on the original solution to IP1.

In many cases, function 14 in department 3 and 19 in department 2 replace functions in departments 4 or 5 in the recommended set. These changes are a result of the modifications in associated functions, constraint matrix, and many of the changes to skill requirements. Additionally, function 17 in department 2 is replaced with other functions when cost coefficients are modified.

The new solutions obtained as a result of the sensitivity analysis of IP1 are used as inputs to both IP2 and IP3. The resulting changes to the solutions of IP2 and IP3 are then examined and summaries are reported in tables 5 and 6.

Looking at table 5 we see that either there are no changes to the solution of IP2 or two contracts are recommended instead of one. This is always driven by the fact that the MDV is very constraining and for this data set is a key parameter.

Table 6 summarizes the sensitivity analysis of IP3. It identifies several scenarios where unsolvable problems are created. This illustrates how tightly the model is constrained. As an example, when the employees performing function 25 in department 4 are replaced with the person performing function 14 in department 3; effect 1 in table 4, the problem becomes unsolvable due to a combination of KC and skill constraints. Several of the other effects also end in a similar result. While KC and skills are important parameters changes to employee's available time result in the most changes to the output.

Effect 9 results in an additional 30 k units of effort that need to be reassigned (a total of 75 k). The model reassigns 49 of these for a ratio of 65 percent. It turns out that "new" employees are reassigned at roughly the same rate as the original set. Effect 9 is also analyzed because it is used to explore the formulation's performance on slightly larger problems. While computing time does not appear to be an issue with this model, the number of constraints may be a consideration. There are nearly 25 000 constraints when solving effect 9 and this number will be considerable larger if the employee's efforts are broken into finer levels such as 10 percent FTE instead of the 25 percent used here.

Overall the formulations appear to function well when tested using the NASA Glenn data. The results of the sensitivity analysis indicate that the outsourcing budget has the most effect in IP1. For a detailed discussion refer to (Kremic, 2003). For IP2, the MDV is the parameter that appears to have the most effect while IP3 is most sensitive to the employee's time available to be reassigned. Another parameter that may also be important to estimate accurately is employee skills. IP3 may terminate in infeasible solutions when the parameters that affect KC functions are changed. This is primarily because the KC requirements are very constraining.

Managerial Implications

The implementation of the DSMPO has many implications to public organizations. First, it is clear that outsourcing decisions are not limited to deciding what to outsource although that is certainly important. The related questions regarding "how to bundle functions into contracts" and "how to reorganize the workforce after outsourcing" also need to be answered. This model helps to answer all three of these questions. The DM can provide strategic and tactical input to the model. This input is captured by the outsourceability index. The index is a reflection of the perceived importance of dominant factors such as political pressure, legal issues, how integrated the function is and how relevant the factors are to a particular function in a particular department. These attributes of the DSMPO can attract managers to use the model to make more systematic decisions about what functions to outsource. It is also known that the reassignment of workers is a complex and cross-functional problem and not easy to solve. The DM is offered a tool in formulation IP3. Utilizing the model with NASA Glenn data reveals that even though a policy may exist to retain the workers, the DM might end up having several workers unassigned to in-house functions due to skills mix or other employee specific issues.

The DSMPO was presented to DM at NASA Glenn as a possible tool to use in deciding additional functions to outsource. However, to date, they have not made the decision to outsource new functions. The political and resource pressures to increase outside support have been handled by hiring more outside help using existing contracts rather than creating new ones.

Conclusions and Recommendations

This study provides outsourcing decision support to public organizations. Such organizations may not be motivated to outsource by cost or strategy issues and therefore existing models may have limited applicability. The DSMPO developed in this study is designed to address the outsourcing dilemma faced by public organizations, which are concerned with several different primary factors beyond cost.

Overall, the DSMPO appears to be a viable model and the three formulations provide optimum decisions regarding what to outsource, the best way to group the outsourced functions into contracts, and the best way to reassign workers. The process for generating the outsourceability indices also appears to be a valuable tool since it brings flexibility in decision making. Furthermore, the three models provide optimum solutions to large problems relatively quickly, and this allows the DM to use commercial solvers, which makes the DSMPO a practical solution tool for outsourcing decisions in public organizations.

This study constitutes an early effort to recognize the unique aspects of outsourcing issues in public organizations. The model is a practical tool for DMs. It may also be useful for adoption by organizations that have similar motives. Broadening the model to incorporate time-based factors may be a valuable extension. Such an extension would allow the DM to predict or track employees' skill development. Yet another extension would be to include different contract types or the ability to input function characteristics such that the model can be more intelligent about allocating functions to make maximum use of economies of scale.

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TABLE I.—DOMINANT FACTORS FOR THE PUBLIC ORGANIZATION OUTSOURCING DECISION

Factor number	Factor	Description/descriptive question	Relative importance
	Strategy		
1	Core	How core is the function to the department or facility?	10
2	Critical knowledge	How important is it to maintain intimate internal knowledge about the function?	10
3	Lack of internal resources	How available are internal resources to perform the function?	10
4	Quality impact	What is the likely impact of outsourcing on current quality?	10
5	Flexibility impact	What is the likely impact of outsourcing on overall flexibility?	8
	Cost		
6	Relative cost	The internal costs required to perform the function relative to the expected costs of purchasing the service from a supplier.	10
	Function Characteristics		
7	Complexity	How complex is the function?	5
8	Integration	How integrated is the function with other processes and systems?	5
9	Asset specificity	How much value do durable goods used or generated by the function have outside of that function?	5
10	Structure	How structured is the function?	5
11	Employees impacted	How many employees are displaced if the function is outsourced?	5
	Environment		
12	External skill availability	How readily can the necessary skills be found externally?	10
13	External politics	Are there external political pressures pushing for or against outsourcing the function?	5
14	Internal politics	Are there internal political pressures pushing for or against outsourcing the function?	5
15	Manager preferences	Are there DM preferences for or against outsourcing the function?	5
16	Legal	Are there legal obstacles, contracts, or agreements impacting the function?	5
17	Competitor's actions	Are competitors outsourcing similar functions?	5
18	Conflict of interest	How likely is it that a conflict of interest would be created by outsourcing the function?	5
19	Degree of uncertainty	How much uncertainty exists in the environment?	5

TABLE II.—FUNCTIONS RECOMMENDED FOR OUTSOURCING

(Function, Department)	General function description
(2, 5)	Administration
(12, 2)	Technician/design
(17, 2)	Engineering
(22, 1)	Administration
(22, 4)	Administration
(23, 2)	Technician/design
(25, 4)	Inspection/quality assurance
(27, 5)	Inspection/quality assurance
(28, 5)	Administration
(28, 6)	Administration

TABLE III.—REASSIGNMENTS OF IP3

(Employee, function, level of effort)	Amount of effort not reassigned
Employee 1—Not reassigned	2 of 2
(2, 18, 1)	1 of 2
(3, 7, 1)	0 of 1
(4, 15, 4)	0 of 4
(5, 3, 1)	0 of 1
(6, 3, 3)	0 of 3
Employee 7—Not reassigned	4 of 4
Employee 8—Not reassigned	4 of 4
(9, 7, 3)	1 of 4
(10, 17, 4)	0 of 4
(11, 13, 4)	0 of 4
(12, 10, 4)	0 of 4
Employee 13—Not reassigned	4 of 4
(14, 8, 4)	0 of 4
Total reassigned (k): 29	Total not reassigned (k): 16

TABLE IV.—CHANGES TO IP1 INPUTS AND THEIR IMPACT TO IP1 SOLUTION

IP1 Solution Number	Type of Modification in IP1	Impact to the ORIGINAL IP1 Solution
1	. Changes in S_{ijk} and W_{ij} . Change in constraint matrix (3)	Function (14, 3) replaced function (25, 4)
2	. Changes in S_{ijk} and W_{ij} . Change in constraint matrix (3)	Function (14, 3) replaced function (27, 5)
3	. Changes in S_{ijk} and W_{ij} . Change in constraint matrix (3)	Function (19, 2) replaced function (25, 4)
4	. Changes in S_{ijk} and W_{ij} . Change in constraint matrix (3)	Function (19, 2) replaced function (27, 5)
5	. Changes in S_{ijk} and W_{ij} . Change in constraint matrix (3)	Functions (14, 3) & (19, 2) replaced both functions (25, 4) & (27, 5)
6	. Change in C_{ij}	Function (20, 2) replaced function (17, 2)
7	. Change in S_{ijk}	Function (20, 2) replaced function (25, 4)
8	. Change in S_{ijk}	Function (14, 3) is added to the recommended set
9	. Change in constraint (1), (2), and (3)	Functions (14, 3) (19, 2) (20, 2) (27, 4) are added to the recommended set

TABLE V.—RESPONSES OF IP2 TO CHANGES IN IP1 INPUT

IP1 solution number	Impact to the solution of IP2	Observations
1	No change	
2	No change (see observation) If two contracts are required: (2, 4, 7) and (1, 3, 5, 6, 8, 9, 10)	If the new function causes the overall contract value to exceed the MDV then two contracts are required.
3	No change	
4	No change (see observation) If two contracts are required: (2, 4, 7) and (1, 3, 5, 6, 8, 9, 10)	If the new function causes the overall contract value to exceed the MDV then two contracts are required.
5	No change	
6	No change	
7	No change	
8	Two contracts instead of one: (3, 4, 7, 11) and (1, 2, 5, 6, 8, 9, 10)	The one additional function doubles the number of variables and computation time required to solve IP2
9	Two contracts instead of one: (1, 5, 6, 7, 11, 12, 13) and (2, 3, 4, 8, 9, 10, 14)	The four additional functions increase the computation time over 10 times.

TABLE VI.—RESPONSES OF IP3 TO CHANGES IN IP1 INPUT

IP1 solution number	Impact to the solution of IP3	Observations
1	Infeasible	When new functions are outsourced the KC requirements must also be reviewed to ensure consistent requirements
2	The employee displaced by outsourcing function 14, in department 3 is reassigned to function 13 at a level of 1. Rest is same.	
3	Infeasible	
4	New reassignments are (4, 8, 3) (4, 15, 1) (13, 18, 1) (14, 15, 3) (14, 8, 1) (18, 1, 2) (19, 1, 2) (20, 1, 1) (21, 9, 1) (22, 1, 3). Rest is same.	
5	Infeasible	
6	New reassignment is (23, 1, 3). Employee 24 not reassigned. Rest is same.	
7	Infeasible	
8	No change to original set.	New employee not assigned; lacked required skills.
9	(2, 18, 1) (3, 7, 1) (5, 11, 1) (6, 3, 3) (9, 7, 3) (10, 15, 2) (10, 17, 2) (11, 15, 4) (12, 13, 3) (12, 17, 1) (14, 15, 2) (18, 1, 2) (19, 12, 2) (20, 1, 1) (21, 9, 1) (22, 1, 3) (23, 1, 2) (23, 3, 1) (25, 10, 4) (27, 17, 1) (27, 7, 3) (27, 8, 1) (28, 8, 3) (28, 13, 1)	Employee 4 now not reassigned. Employees 24 and 29 not reassigned.

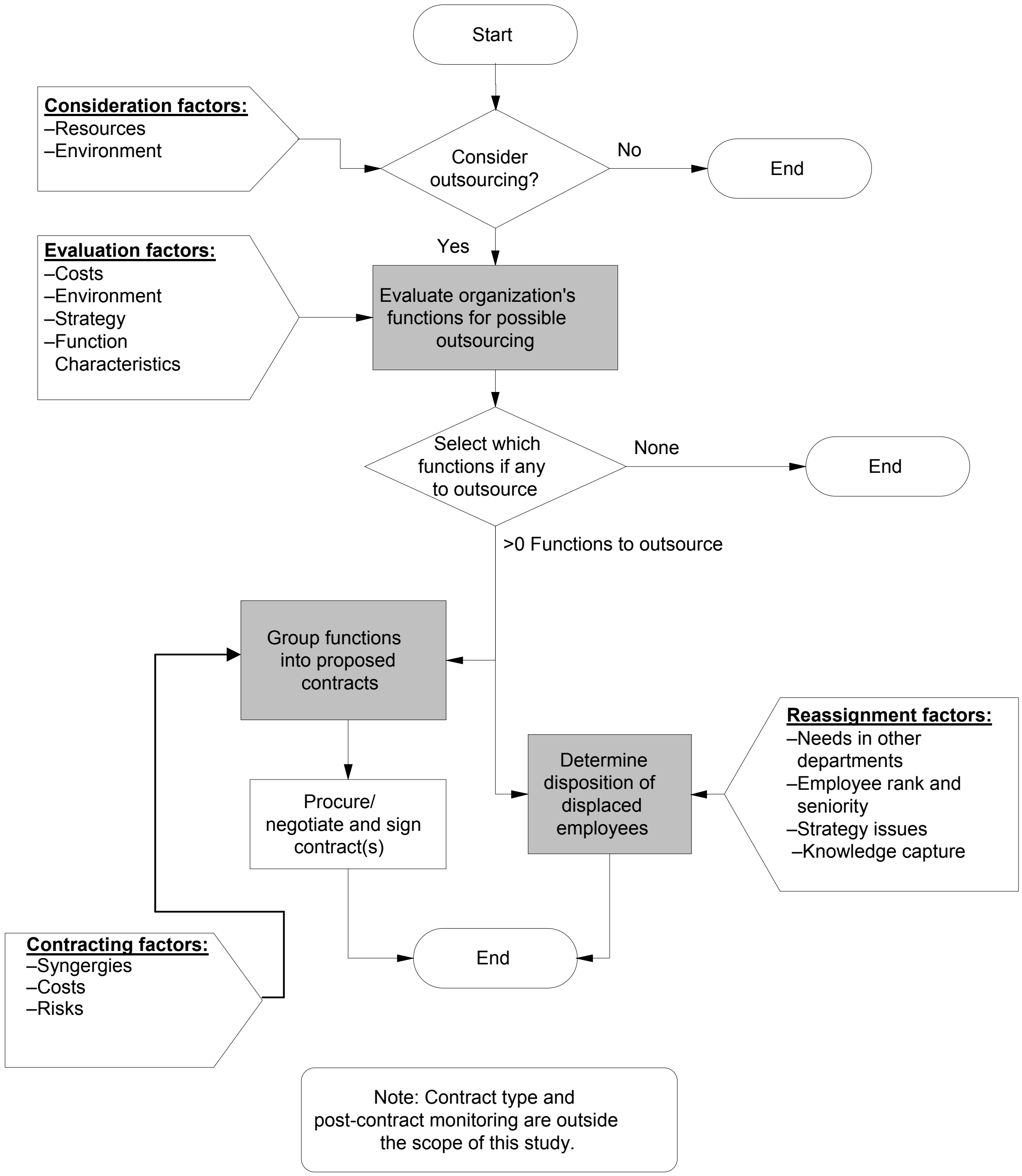

Figure 1.—Outsourcing decision flow chart.

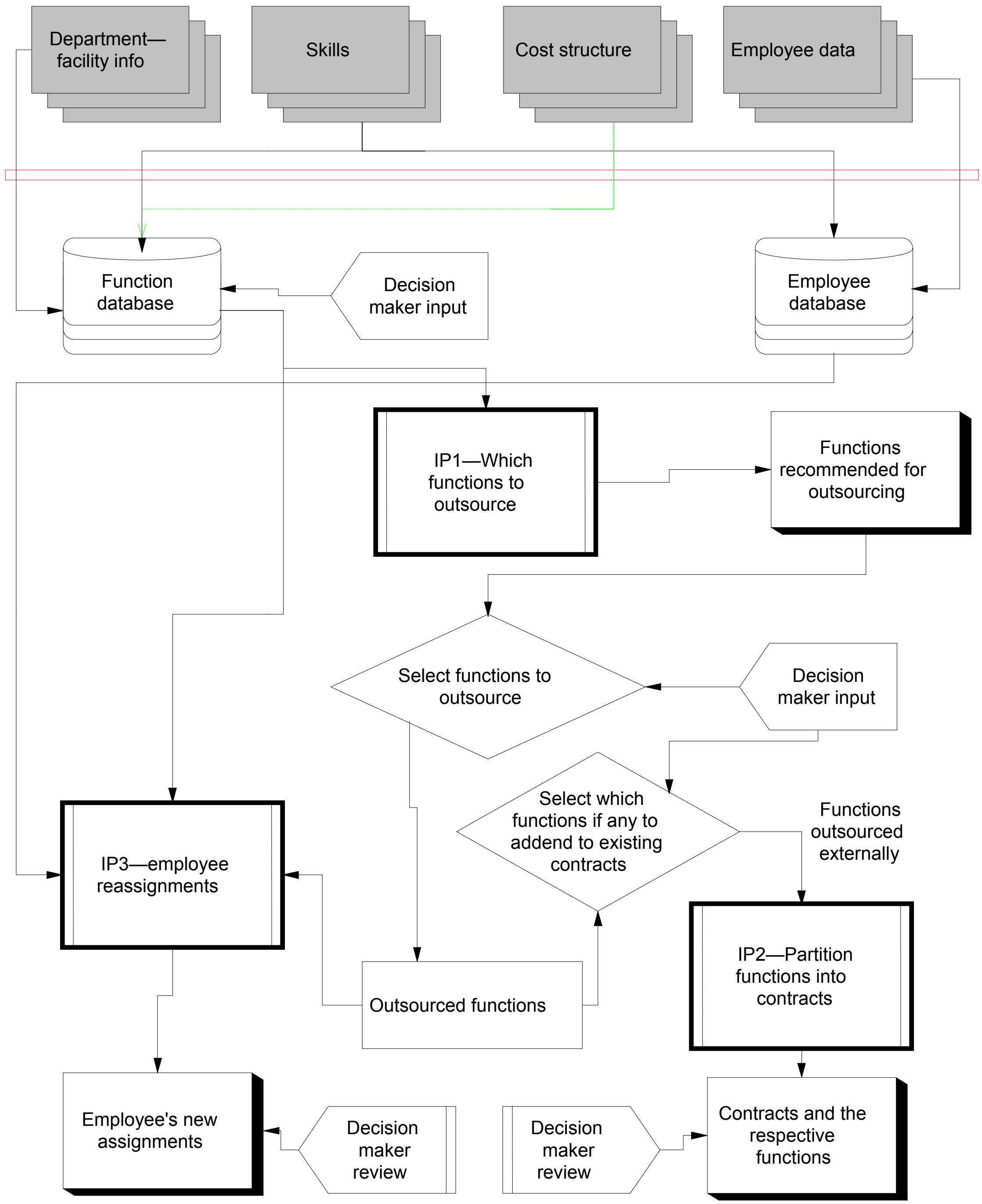

Figure 2.—Outsourcing decision support model for public organizations (DSMPO).

Department 1

Function Number	Function Name	Skills Required	Associated Functions	Dis-Associated Functions	Knowledge Capture Function?	Capture Effort (FTE)	Min. Required Grade	Total Current Effort (FTE)	Estimated Annual Cost (K)	Additional Capacity for FTEs?	Inherently Gov?
1	LM	**	**	**	**	**	**	1	**	**	Yes
2	MS	3	None	None	No	NA	6	1	50	No	No
3	PM	2, 5, 8	5	None	Yes	0.5	9	1.5	75	No	No
4	RPA	7	None	6	No	NA	6	2	53	No	No
5	MPM	3, 5, 8	3	None	No	NA	8	1.5	68	No	No
6	OA	4	None	4	No	NA	4	1	40	Yes	No

** Note: Function 1 is inherently governmental and will not be considered for outsourcing. No additonal data collected

Employee Number	Grade	Years of Service	Current Functions Performed	Level of effort for each Function (25% increments)	Skills Possessed
1	6	17	2	100	3, 7
2	7	32	4	100	7
3	9	18	5	100	3, 5, 8
4	7	23	4	100	3, 7
5	9	43	3, 5	50, 50	2, 3, 5, 8
6	10	27	1	100	1, 5, 9, 12
7	4	23	6	100	4
8	8	20	3	100	2, 5, 8

Figure 3.—A sample of input data.

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13. ABSTRACT ***(Maximum 200 words)***

There has been a tremendous growth in outsourcing practices in recent years. The public organizations in the United States have outsourced some functions and are now being compelled to outsource additional ones. While there are numerous studies that document and analyze outsourcing practices, there is limited research to guide public or governmental organizations in determining what functions to outsource. This study fills this gap by developing a decision support model for a typical public organization in determining what to outsource and how. A set of outsourcing decision factors is identified that can be used as parameters in the three integer programming formulations developed. These formulations are used as solution engines in the model. The first formulation identifies which functions are the best candidates for outsourcing given the organization's priorities. The other formulations place the functions into recommended contracts and re-assign displaced employees. Data from NASA Glenn Research Center in Ohio is used to test and analyze the model. Analysis indicates that cost and skills-related factors are the most sensitive parameters for the data tested. The model and the formulations are a relatively comprehensive package and may help guid outsourcing decisionmakers and policymakers in public organizations.

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